EXPERIENCES OF THE TROUBLE FOR EXTRACTION SEPTA AT THE KEK 12 GEV-PS MAIN RING

14th ICFA Mini-Workshop on septa devices
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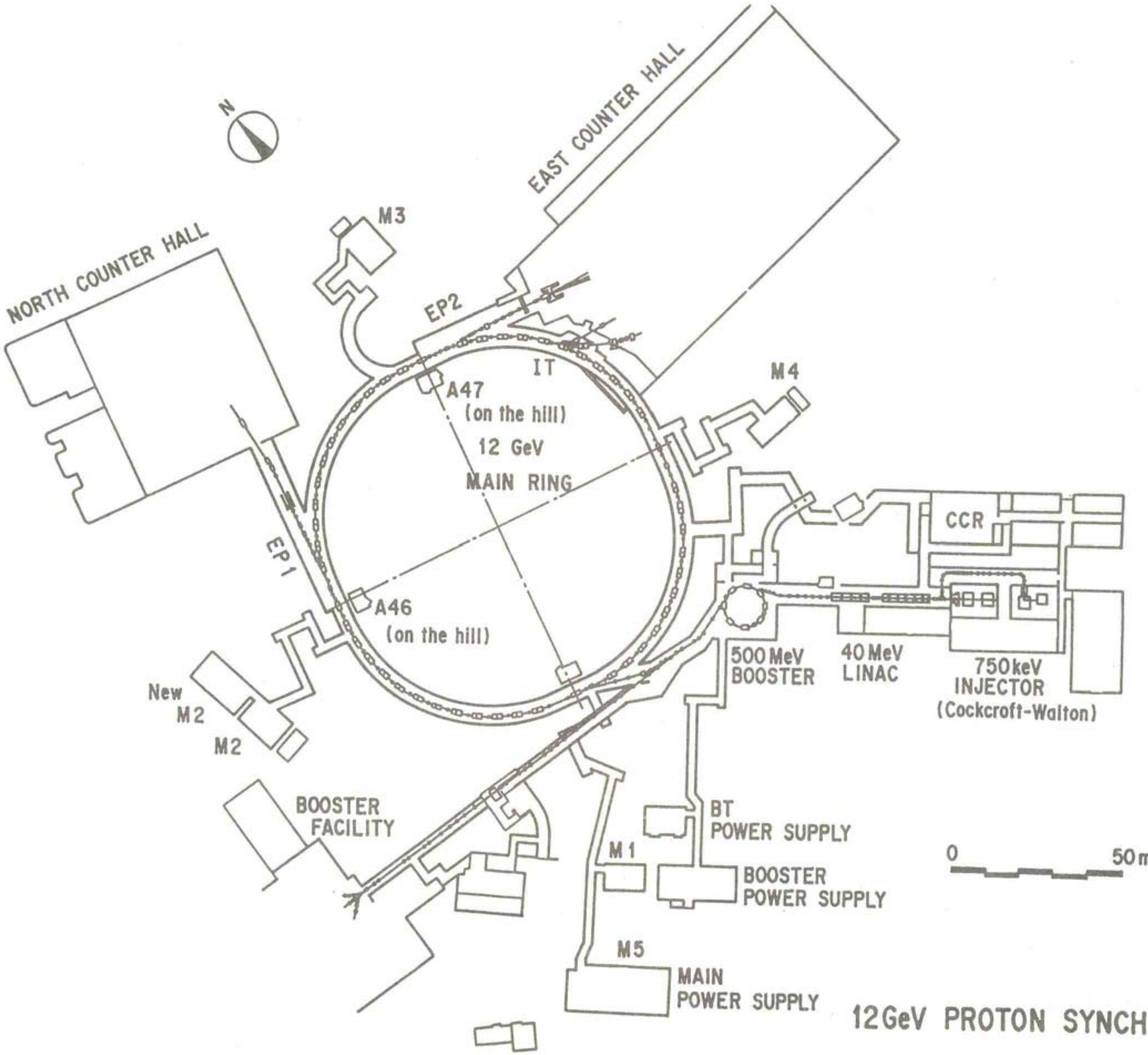
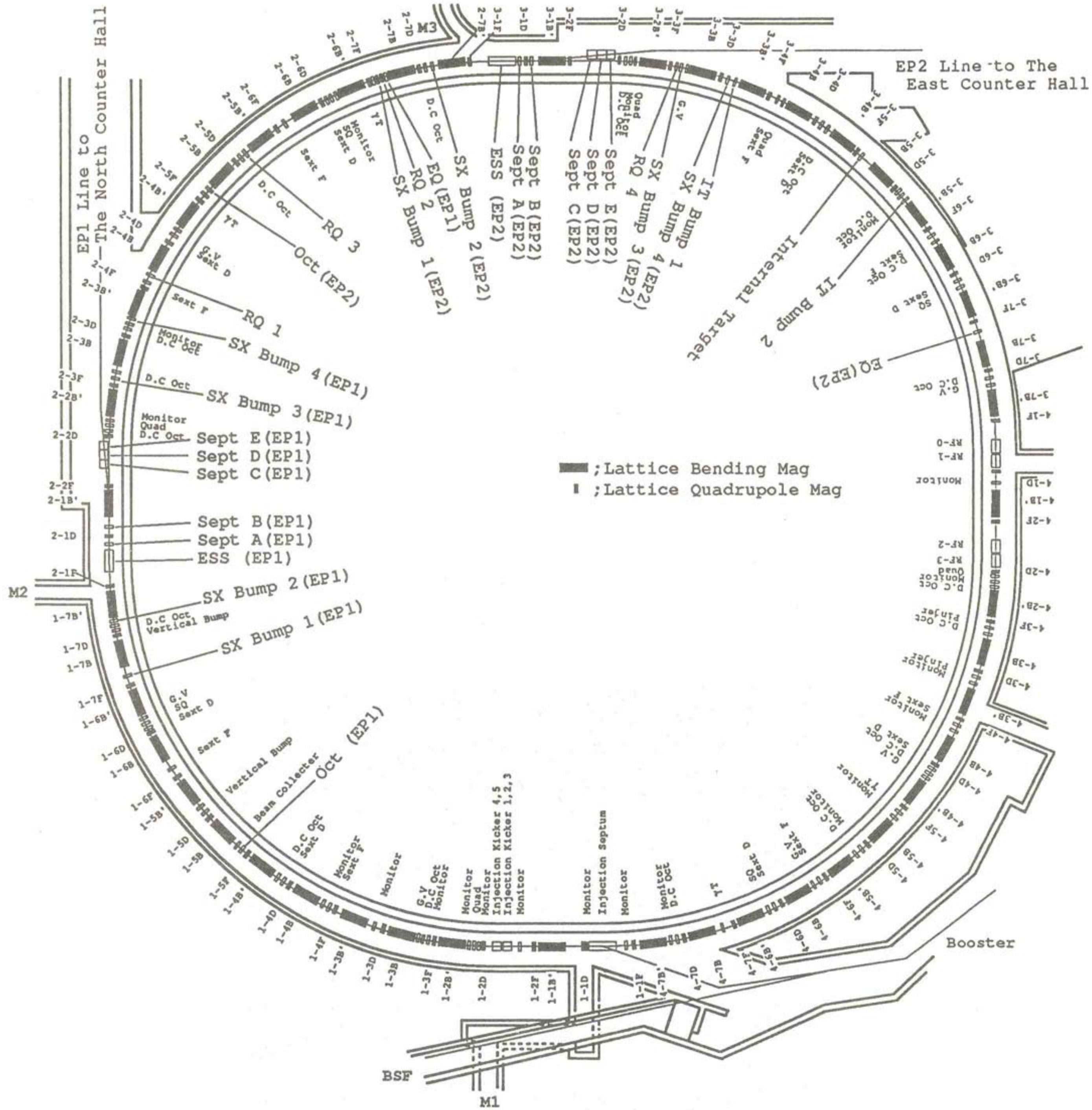
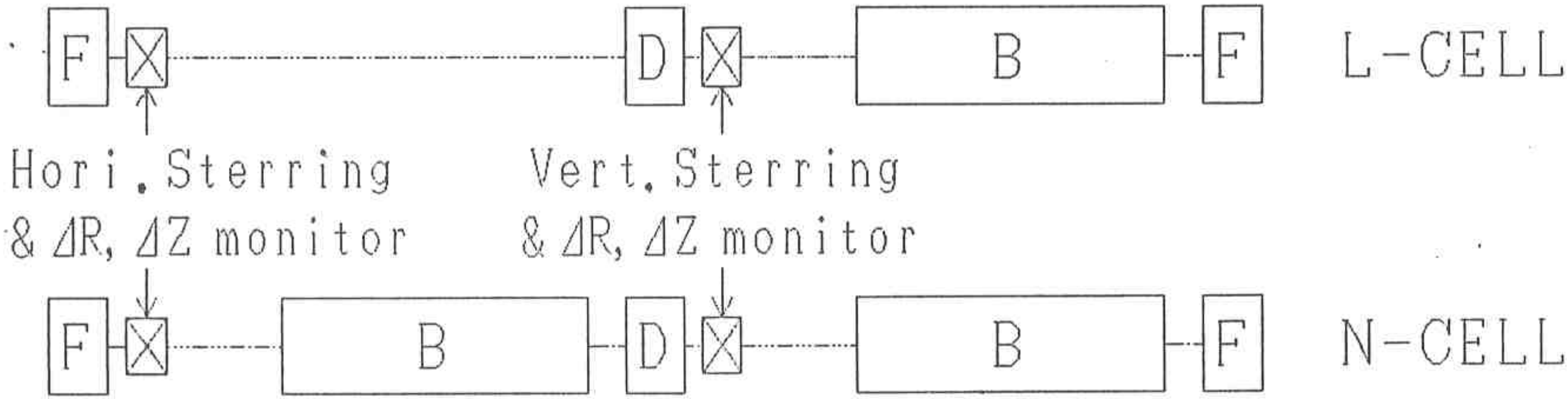
- ■ 12 GeV-PS Main Ring and the Slow Extraction Scheme
- ■ Experiences of the trouble for extraction septa
- ■ Conclusion



12GeV PROTON SYNCHROTRON



EP1 Line to The North Counter Hall
EP2 Line to The East Counter Hall
M1
M2
M3
BSF
Booster
;Lattice Bending Mag
;Lattice Quadrupole Mag
SX Bump 1(EP2)
SX Bump 2(EP2)
RQ 2
EQ(EP1)
ESS (EP2)
Sept A(EP2)
Sept B(EP2)
Sept C(EP2)
Sept D(EP2)
Sept E(EP2)
RQ 4
SX Bump 3(EP2)
SX Bump 4(EP2)
IT Bump 1
Internal Target
IT Bump 2
EQ(EP2)
RQ 3
Oct(EP2)
RQ 1
SX Bump 4(EP1)
SX Bump 3(EP1)
Sept E(EP1)
Sept D(EP1)
Sept C(EP1)
Sept B(EP1)
Sept A(EP1)
ESS (EP1)
SX Bump 2(EP1)
SX Bump 1(EP1)
Oct (EP1)
Beam Collecter
Vertical Bump
Injection Kicker 4,5
Injection Kicker 1,2,3
Injection Septum
Monitor
D.C Oct
Sext F
Sext D
G.V
SQ
Quad
RF-0
RF-1
RF-2
RF-3


F
D
B
F
L-CELL
Hori. Sterring
& ΔR, ΔZ monitor
Vert. Sterring
& ΔR, ΔZ monitor
F
B
D
B
F
N-CELL


L L N N N N N
ONE SUPER PERIOD

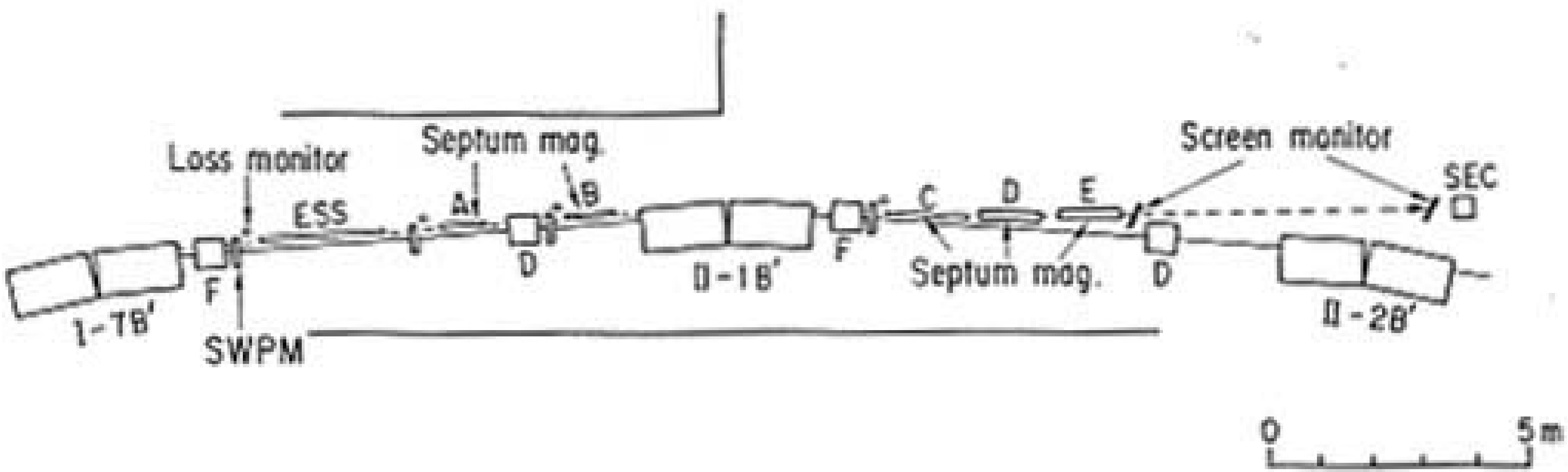

Loss monitor
Septum mag.
ESS
A
B
Screen monitor
SEC
C
D
E
F
D
I-18'
F
Septum mag.
D
I-17B'
II-28'
SWPM
0
5m

Table2

Main Accelerator Parameters

A. Energy and Magnetic Fields

At Final Energy		
Maximum Kinetic Energy	T max	12 GeV (8 GeV*)
Maximum Momentum	p max	12.9042 GeV/c (8.8889 GeV/c)
Maximum Field Strength of Bending Magnets	B max	17.5 kG (12.06 kG)
Maximum Field Gradient of Quadrupole Magnets	$\left(\frac{\partial B}{\partial X}\right)max$	1.7623 kG/cm (1.2139 kG/cm)
At Injection		
Injection Kinetic Energy	T inj	500 MeV
Injection Momentum	P inj	1.0901 GeV/c
Field Strength of bending Maunets at Injection	B inj	1.4783 kG
Field Gradient of Quadrupole Magnets at Injection	$\left(\frac{\partial B}{\partial X}\right)inj$	0.1489 kG/cm

B. Physical Dimensions

Average Radius	R	54m
Circumference	C	339.29m
Bending Radius	ρ	24.5966m
Number of Superperiods	N_S	4
Number of Periods	N	28
Normal Periods		20
Periods Forming Long Straight Sections		8
Length of a Period	L_P	12.1176m
Number of Bending Magnets (Consisting of Two Core Units)	N_B	48
Number of Quadrupole Magnets	N_Q	56
Focusing Ones		28
Defocusing Ones		28
Effective Length of Bending Magnets	L_B	3.2197m
Core Length of Bending Magnets		1.61mx2
Effective Length of Quadrupole Magnets	L_Q	0.6m
Core Length of Quadrupole Magnets		0.60m
Length of a short Straight Section	L_{SSS}	1.8391m
Length of a Long Straight Section	L_{LSS}	5.4588x2

C. Orbit Parameters

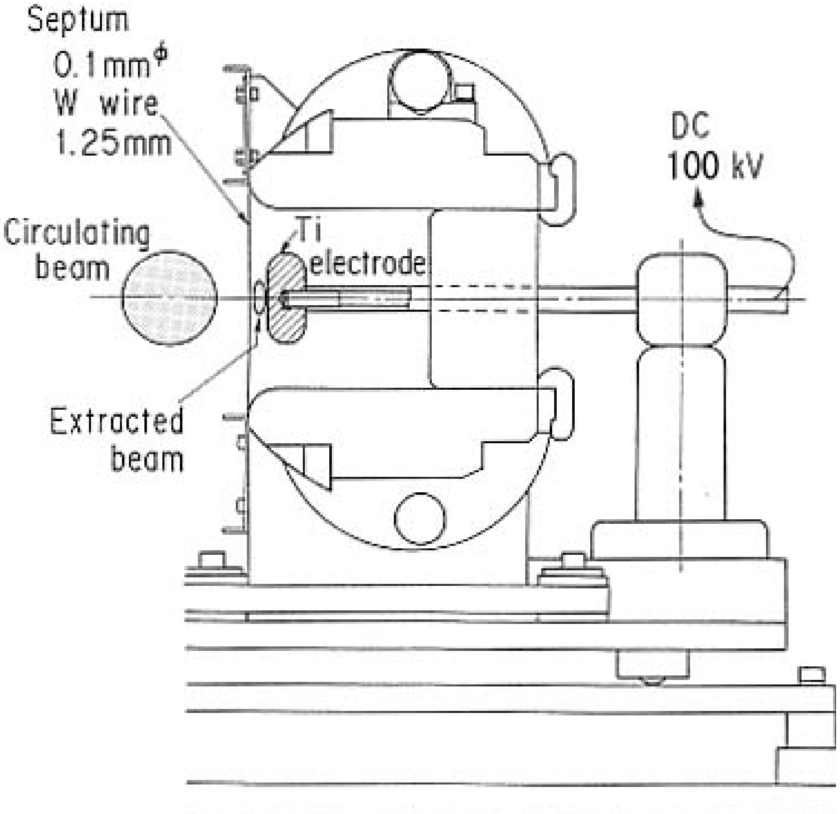
Normal Betatron Wave Number (Number of Betatron Oscillations per Revolution)	υ	7.25
Average Momentum Compaction Factor	α_P	0.02191
Total Transition Energy over Rest Energy	γ_t	6.76
Transition Kinetic Energy	T_t	5.4 GeV
Maximum and Minimum	β	
in Bending Magnets	$(\beta_H)max$	18.00m
	$(\beta_V)max$	17.83m
	$(\beta_H)min$	3.99m
	$(\beta_V)min$	3.99m
in Quadrupole Magnets	$(\beta_H)max$	20.44m
	$(\beta_V)max$	20.45m
	$(\beta_H)min$	3.36m
	$(\beta_V)min$	3.36m
Average β Value	$\beta av=R/\upsilon$	7.448m
From Factor	F	2.75
Maximum Dispersion Function		
in Bending Magnets	$(X_P)max$	3.35m
in Quadrupole Magnets		3.84m

D. Apertures of Magnets and Acceptance

Useful Semi-Aperture of Bending Magnets		
Horizontal		70mm
Vertical		25mm
Height of Bending Magnet Gap		56mm
Bore Radius of Quadrupole Magnets		50mm
Horizontal		70mm
Vertical		27mm
Acceptance at 500 MeV**		
Horizontal	A_H	81.5πmm.mrad
Vertical	A_V	19.6πmm.mrad

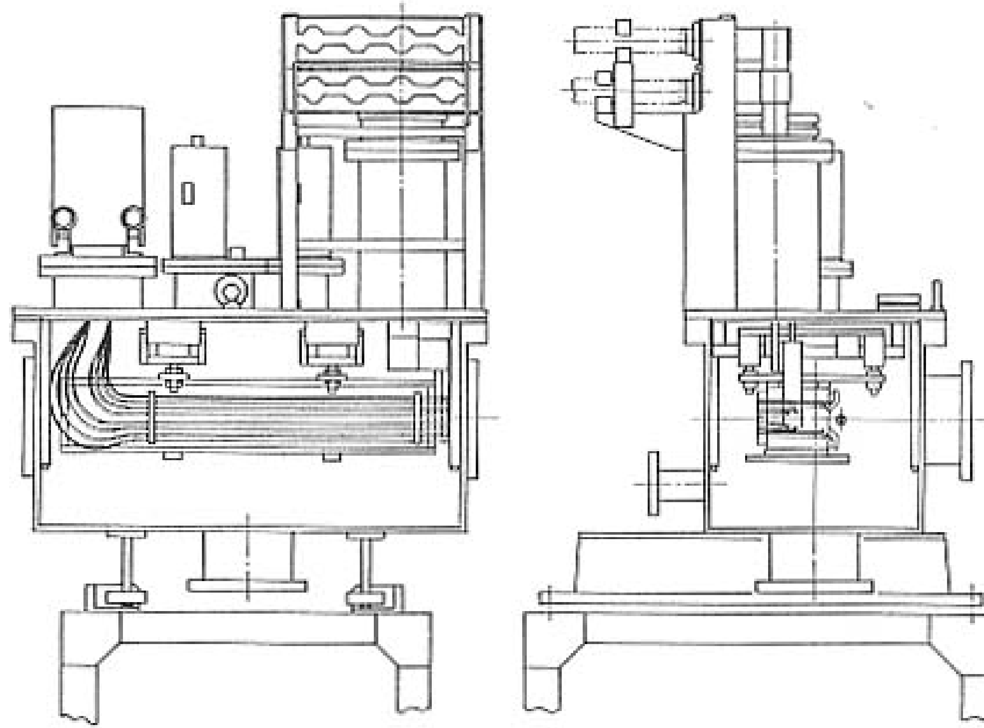
E. RF Acceleration

Revolution Frequency		
at Injection	f inj	0.66968 MHz
at Final Energy	f_f	0.88126 Mhz (0.8781 Mhz)
Harmonic Number of RF	h	9



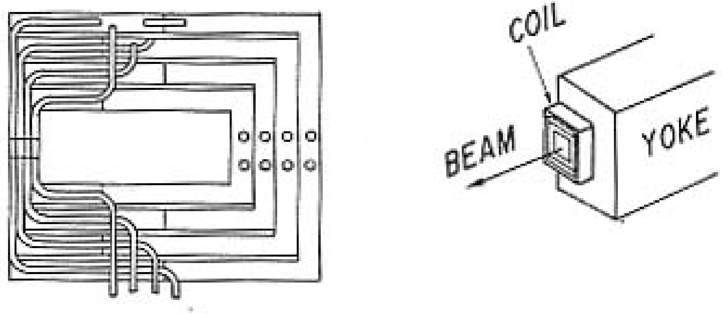
ESS

Septum Magnet A,B

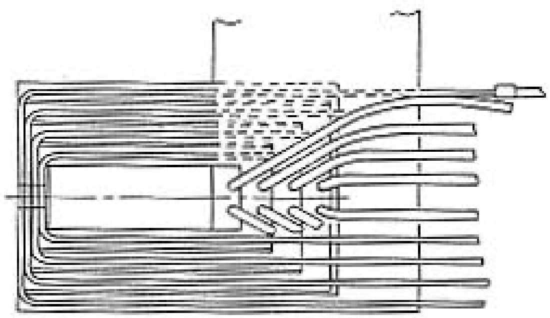


Septum Magnet C, D, E

(a)



(b)



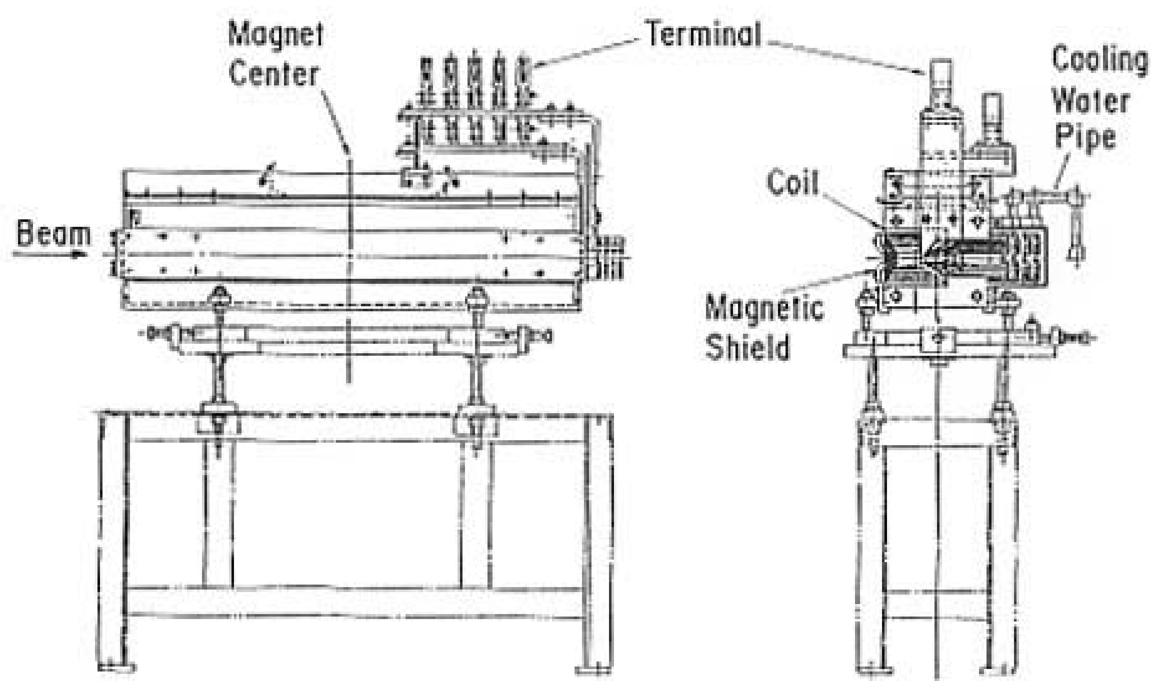


Table I Parameters of the extraction magnets. RQ1 and RQ2 are identical. RQ3 and RQ4 are the same type magnets. The core length and bore radius of RQ3 and 4 are the length and mean radius of air-core coils. The data concerning water cooling are bench test results.

magnets	EQ	OCT	RQ1, 2	RQ3, 4
weight (kg)	220	200	90	
gap (mm)	43.60	25.85	43.60	
core length (mm)	200	160	60	250
bore radius (mm)	62	80	62	80
coil turn (per pole)	22	18	24	14
resistance (mΩ)	38	52	55	84
inductance (mH)	5	8	1.5	0.38
maximum current (A)	500	500	30	30
maximum voltage (V)	60	60	200	30
max field (T/m, T/m^3)	7.21	1130	0.3	0.16
cooling water circuit	4	4	air	air
water press. (kg/cm^2)	10	10		
water press. loss	4	4		
water flow (l/min)	4	7		

Table II Parameters of the extraction bump magnets. Bump magnets 2, 3 and 4 are identically the same type of magnet.

magnets	Bump1	Bump2,3,4
weight (kg)	200	460
pole gap (mm)	62	62
core length (mm)	170	430
gap width (mm)	200	200
coil turn (by pole)	42	42
resistance (mΩ)	40	60
inductance (mH)	7	17
maximum current (A)	250	250
maximum voltage (V)	55	55
max field (T)	0.21	0.21
cooling water circuit	2	2
pressure (kg/cm^2)	10	10
pressure loss (kg/cm^2)	5	5
water flow (l/min)	2.6	1.9

Table III Parameters of the current regulated power supplies for the extraction magnets. There are four types of power supplies, and one power supply for one magnet. The power supplies for the RQs are precision power amplifiers: 4520 (NF Electric Instrument Corp.). All power supplies are cooled by air.

	EQ, OCT	RQ1-4	Bump1	Bump2-4
width (mm)	1500	440	700	700
height (mm)	1800	510	1800	1800
depth (mm)	1000	690	900	900
max current (A)	500	15	250	250
max voltage (V)	60	$\pm$200	35	55
stability (%)	0.1	< 2	0.1	0.1
ripple (%)	0.01	20 mV	0.1	0.1
response	300 Hz	20 kHz	10ms	10ms
time lag(ms)	1, 0.8	–	8	8, 6, 4
source	400V 3ϕ	200V 1ϕ	200V 3ϕ	200V 3ϕ

Table IV Parameters of the extraction septa.

* The horizontal aperture is variable

** Height of Ti cathode. Yoke aperture is 100 mm

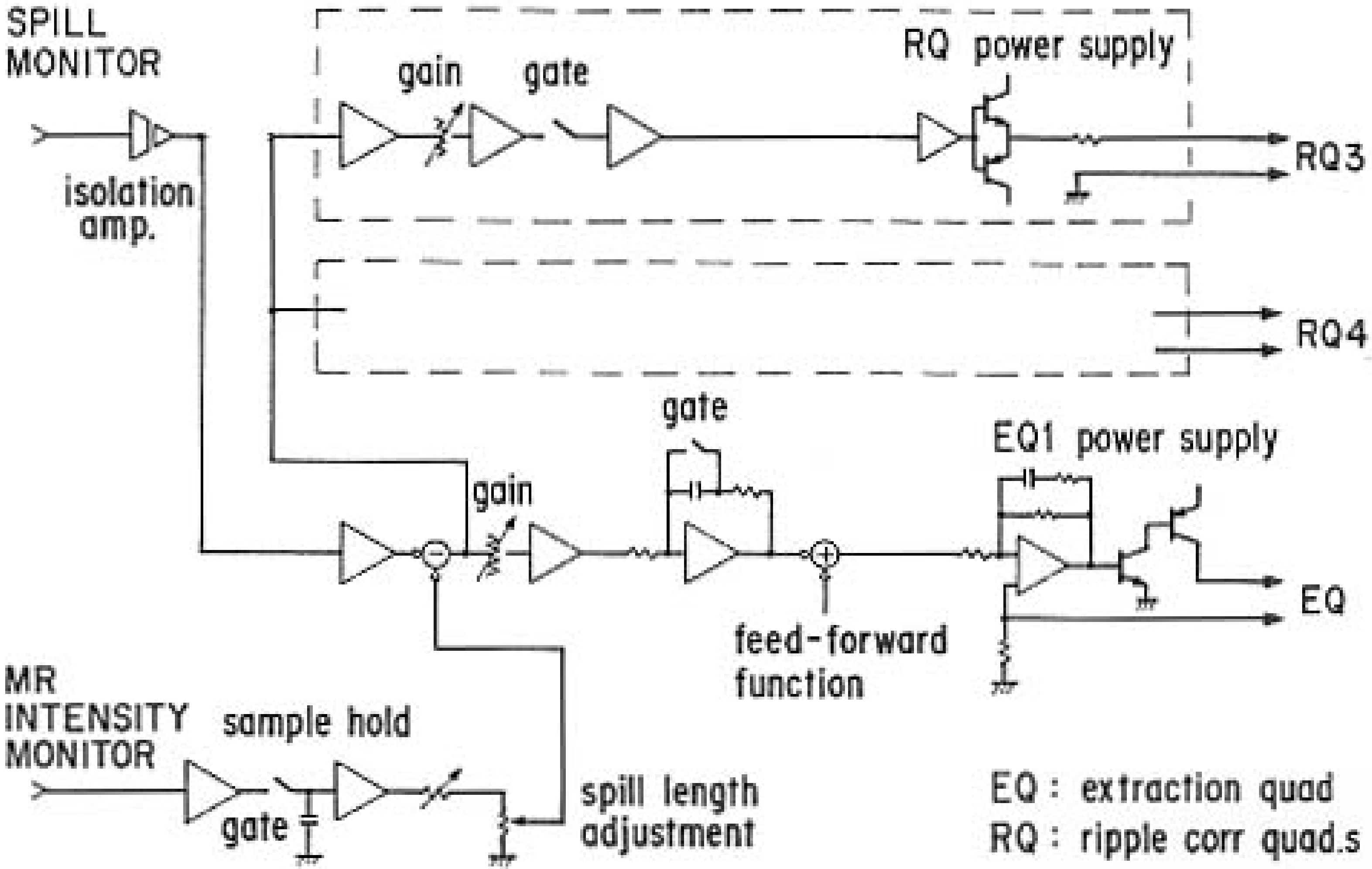
septum	ESS	Sep.A	Sep.B	Sep.C	Sep.D, E
thickness(mm)	0.1	1.0	2.0	16.0	32.0
coil turn		1	2	4	8
length(m)	1.5 X 2	0.9	0.7	1,5	1.3
field strength	6MV/m	0.08T	0.16T	0.8T	1.6T
hor. aperture (mm)	10-40*	62	47	91	75
ver. gap (mm)	50**	35	35	34	34
environment	vacuum	vac.	vac.	air	air
deflection angle(mrad)	1.4	1.6	2.5	28	49

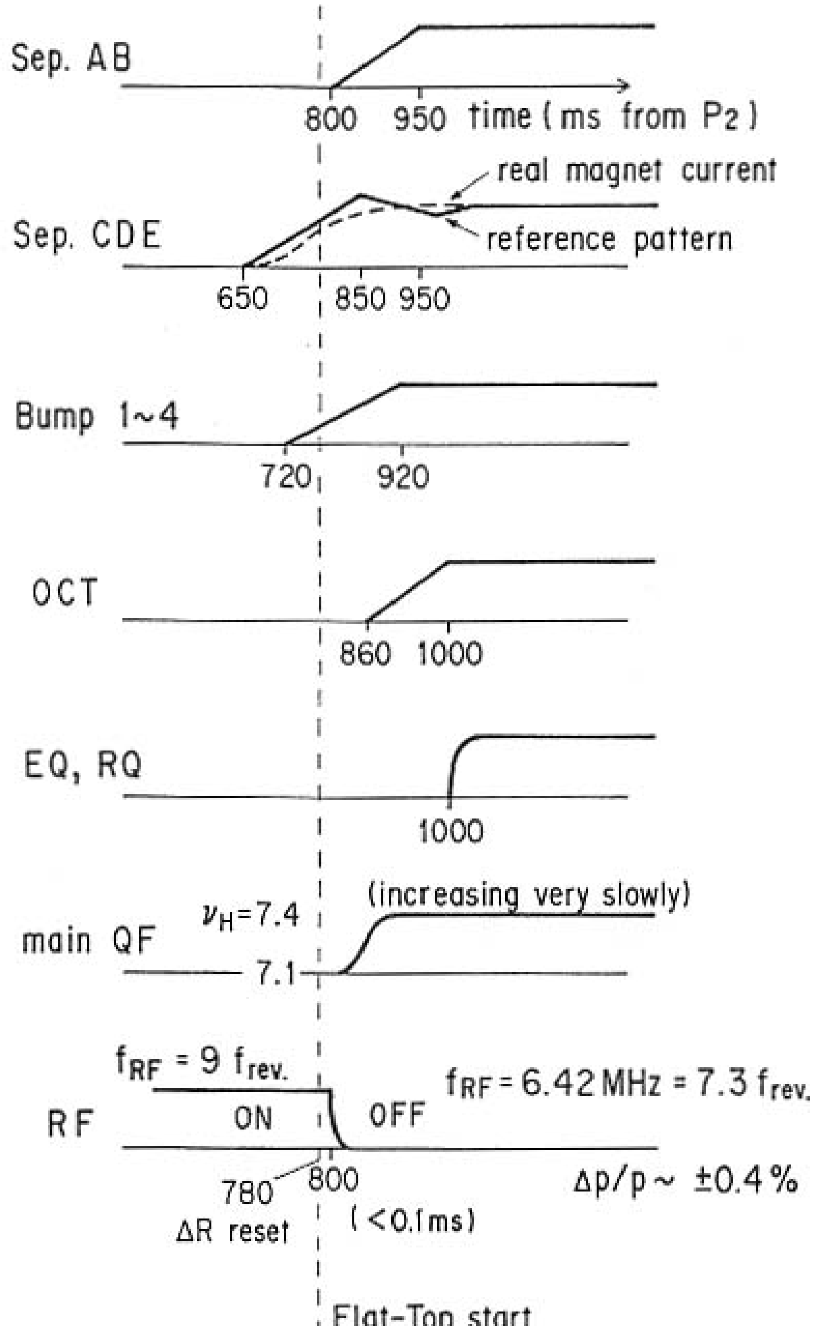
Table V Parameters of the DC high voltage supply for the ESS.
(Nichicon DCG-200K3M)

maximum out put voltage	200	kV
limit current	3	mA
stability	< 1	% for AC source 100V ± 10%
ripple	< 1	% at 200kV 3mA operation
Source	AC 100V 50Hz 1	

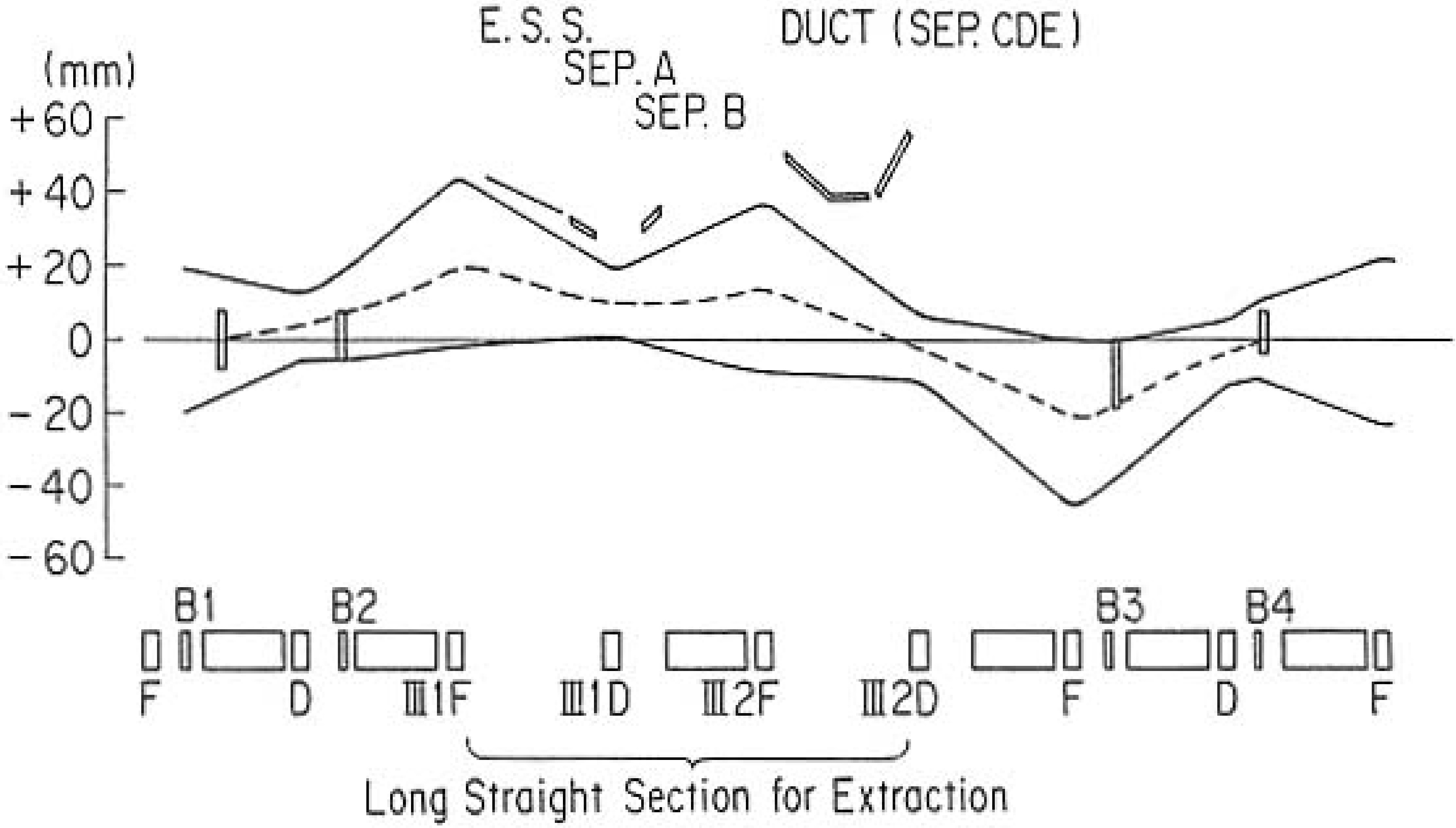
Table VI Parameters of the current regulated power supply for the magnetic septum. Two septa, A and B, are connected in series to one power supply. Three septa, C, D and E, are connected in series to one power supply. Though the frame sizes are different for EP1 and EP2, the performance of the power supplies are the same.

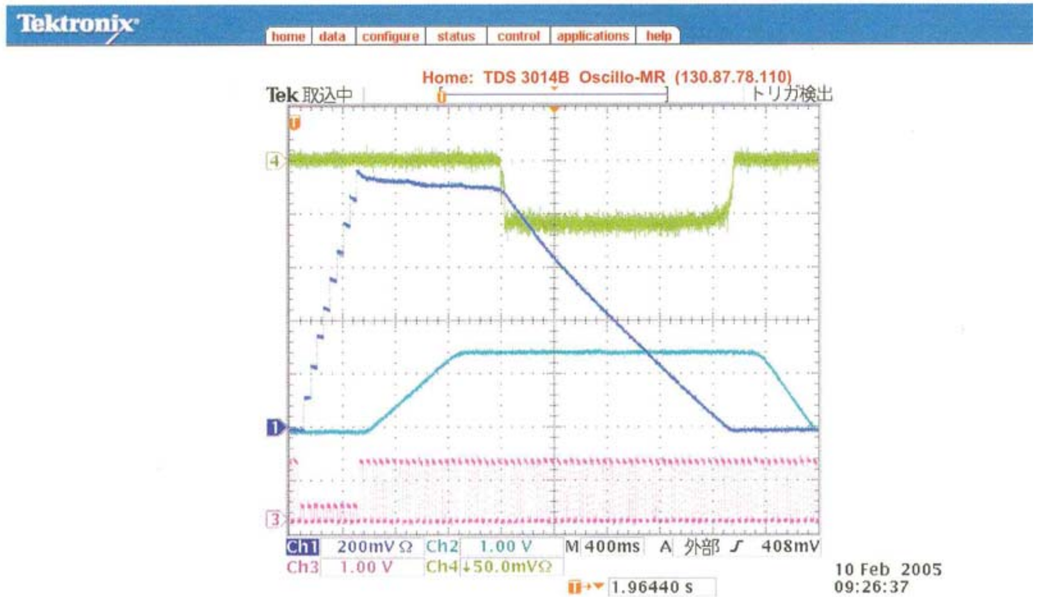
	Sep.A,B	Sep.C,D,E
width EP1/EP2 (m)	3.3 /4.8	6.0 /7.5
height EP1/EP2 (m)	2.75/2.35	2.75/2.35
depth (m)	1.5	1.5
regulation current (A)	330-3300	600-6000
maximum voltage (V)	20	120
maximum power (kW)	66	720
reproducibility (%)	< ± 0.1	< ± 0.1
non-linearity (%)	< ± 0.1	< ± 0.1
ripple (%)	0.025	0.015
response time (ms)	10	10
Source	400V 3ϕ	400V 3ϕ
cooling	forced air	forced air


SPILL MONITOR
isolation amp.
gain
gate
RQ power supply
RQ3
RQ4
gate
EQ1 power supply
gain
EQ
feed-forward function
MR INTENSITY MONITOR
sample hold
gate
spill length adjustment
EQ : extraction quad
RQ : ripple corr quad.s



Sep. AB
800
950
time (ms from P2)
real magnet current
Sep. CDE
reference pattern
650
850
950
Bump 1~4
720
920
OCT
860
1000
EQ, RQ
1000
(increasing very slowly)
ν_H=7.4
main QF
7.1
f_{RF} = 9 $f_{rev.}$
f_{RF} = 6.42 MHz = 7.3 $f_{rev.}$
RF
ON
OFF
780
800
$\Delta p/p \sim \pm 0.4\%$
ΔR reset
(<0.1ms)
Flat-Top start


E. S. S.
SEP. A
SEP. B
DUCT (SEP. CDE)
(mm)
+60
+40
+20
0
−20
−40
−60
B1
B2
B3
B4
F
D
III1F
III1D
III2F
III2D
F
D
F
Long Straight Section for Extraction

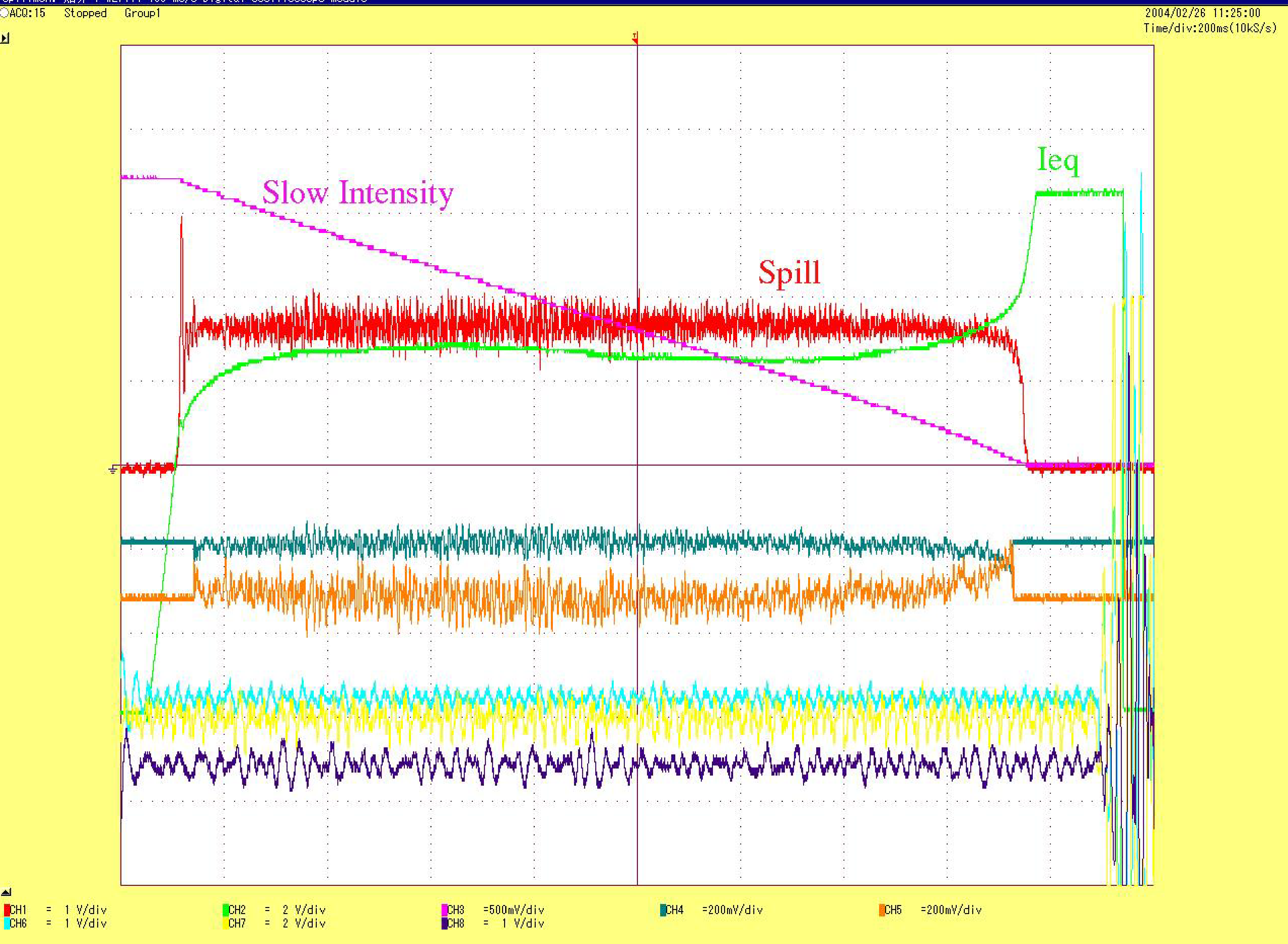


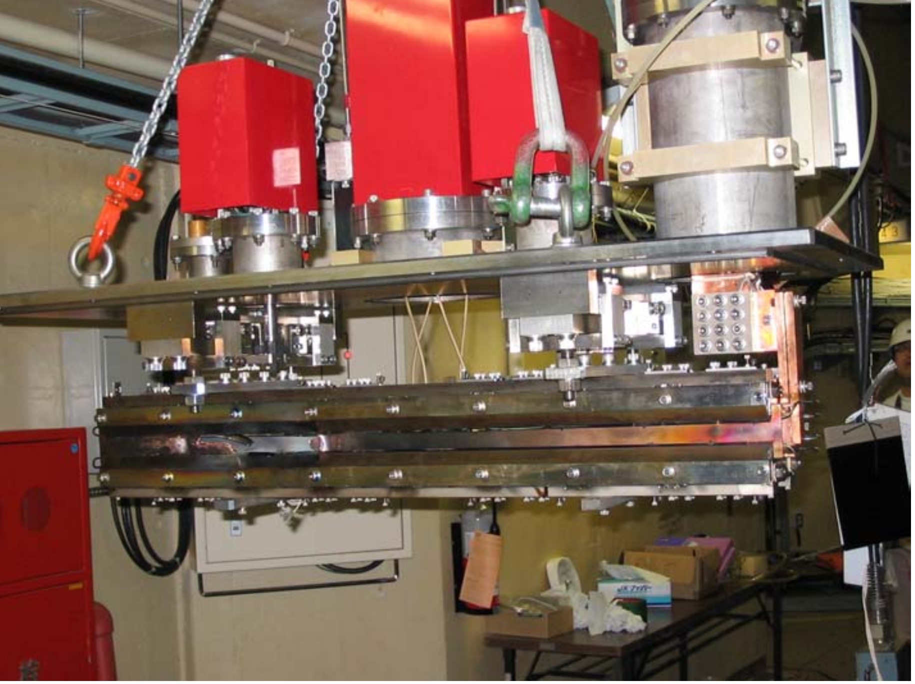
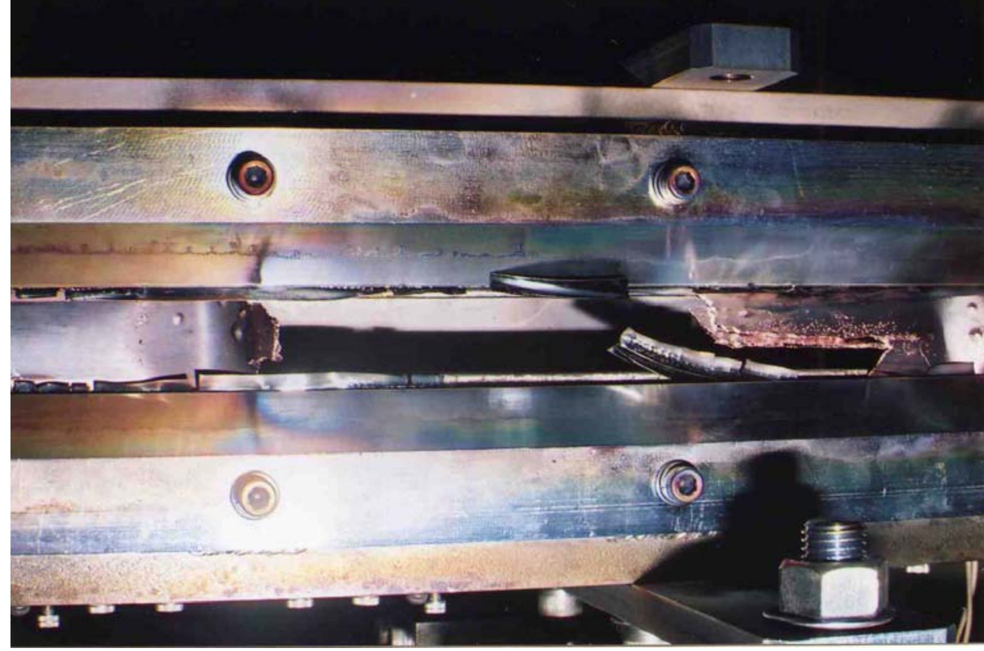
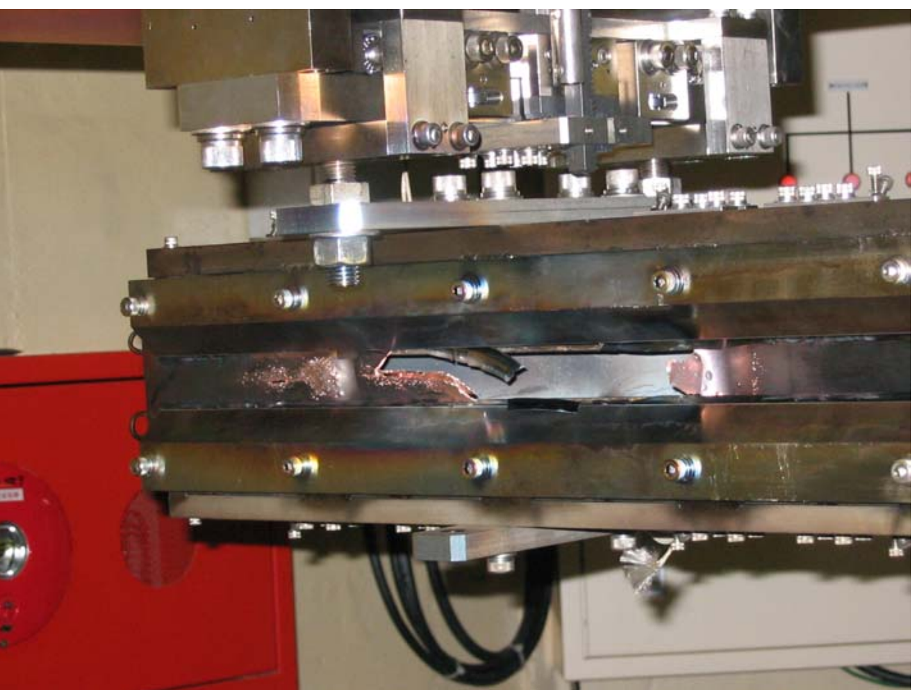
-----INTENSITY----- TIME 2005/02/08 18:49:47

CM2(ION1)	21.8 mA			pulse width NML[40.] μs
CM2(ION2)	0.0 mA			MR [9.] μs
CM-7	14.6 mA	<<MR>>		
20MeV	11.6 mA	BSTR	5.5 E11 ppp	BSTR >> 500MeV [ ]%
40-1	10.6 mA	K1	4.9 E11 ppp	BSTR >> MR INJ [ ]%
40-3	10.5 mA	P2	3.9 E12 ppp	Linac 20MeV & 40MeV Energy
40-1/CM7	73 %	P3	3.8 E12 ppp	by Beta Monitor
				Proton 20BT 20.00 MeV
BSTR	23.0 E11 ppp	EP2	3.3 E12 ppp	Proton 40BT 40.37 MeV
NML	22.1 E11 ppp	IT	4.5 E11 ppp	
effic.	97 %	Duty	87 %	Proton 40BT2 40.26 MeV

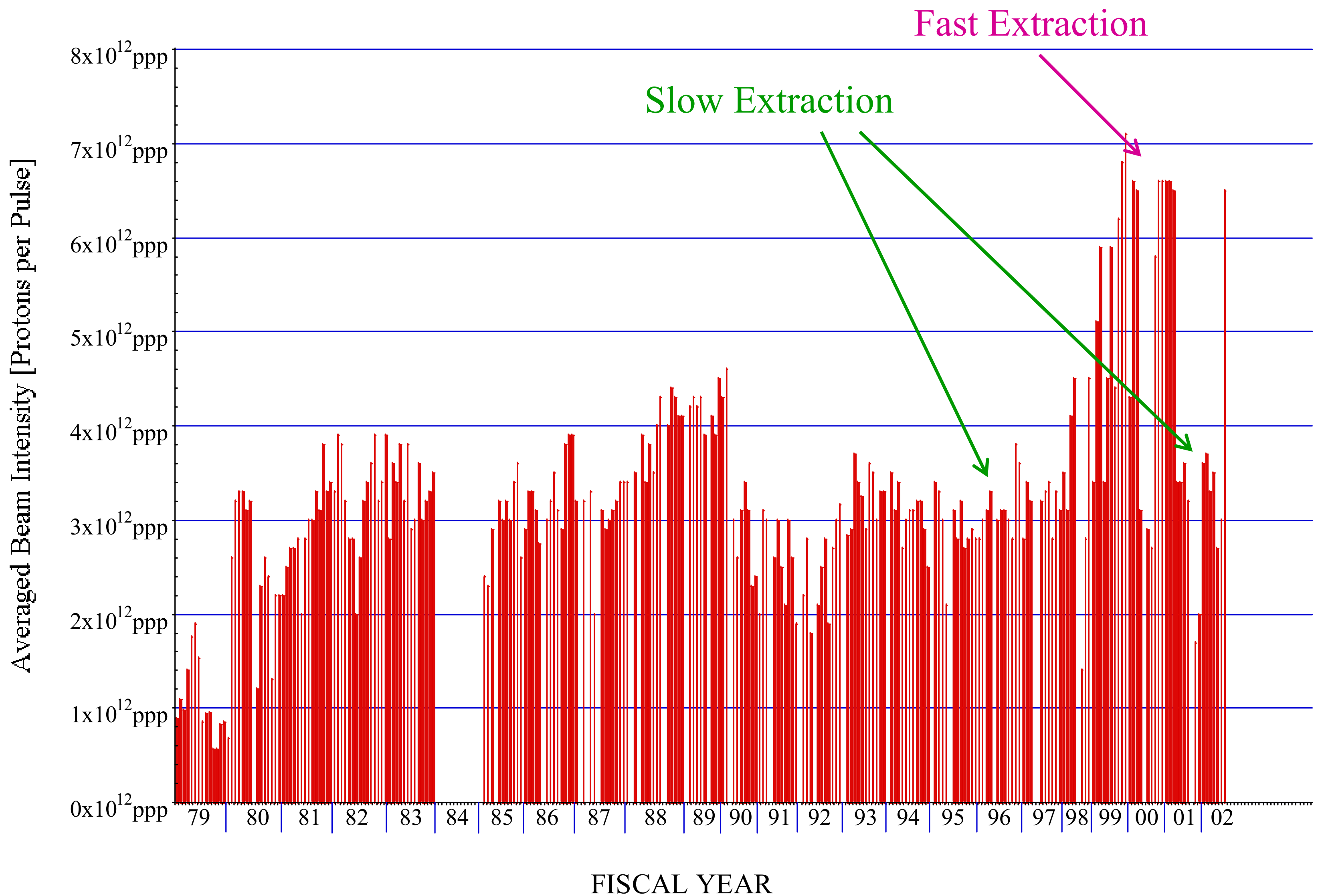
-----INTENSITY----- TIME 2005/02/09 16:55:51

CM2(ION1)	21.6 mA			pulse width NML[38.] μs
CM2(ION2)	0.0 mA			MR [9.] μs
CM-7	14.4 mA	<<MR>>		
20MeV	11.6 mA	BSTR	5.5 E11 ppp	BSTR >> 500MeV [ ]%
40-1	10.5 mA	K1	5.0 E11 ppp	BSTR >> MR INJ [ ]%
40-3	10.3 mA	P2	4.0 E12 ppp	Linac 20MeV & 40MeV Energy
40-1/CM7	72 %	P3	3.8 E12 ppp	by Beta Monitor
				Proton 20BT 19.99 MeV
BSTR	22.0 E11 ppp	EP2	3.3 E12 ppp	Proton 40BT 40.39 MeV
NML	21.3 E11 ppp	IT	4.4 E11 ppp	
effic.	97 %	Duty	85 %	Proton 40BT2 40.25 MeV


ACQ:15 Stopped Group1
2004/02/26 11:25:00
Time/div:200ms(10kS/s)
Slow Intensity
Ieq
Spill
CH1 = 1 V/div
CH2 = 2 V/div
CH3 =500mV/div
CH4 =200mV/div
CH5 =200mV/div
CH6 = 1 V/div
CH7 = 2 V/div
CH8 = 1 V/div


History of the Averaged Intensity of the Main Ring



Residual Activity in the M.R.

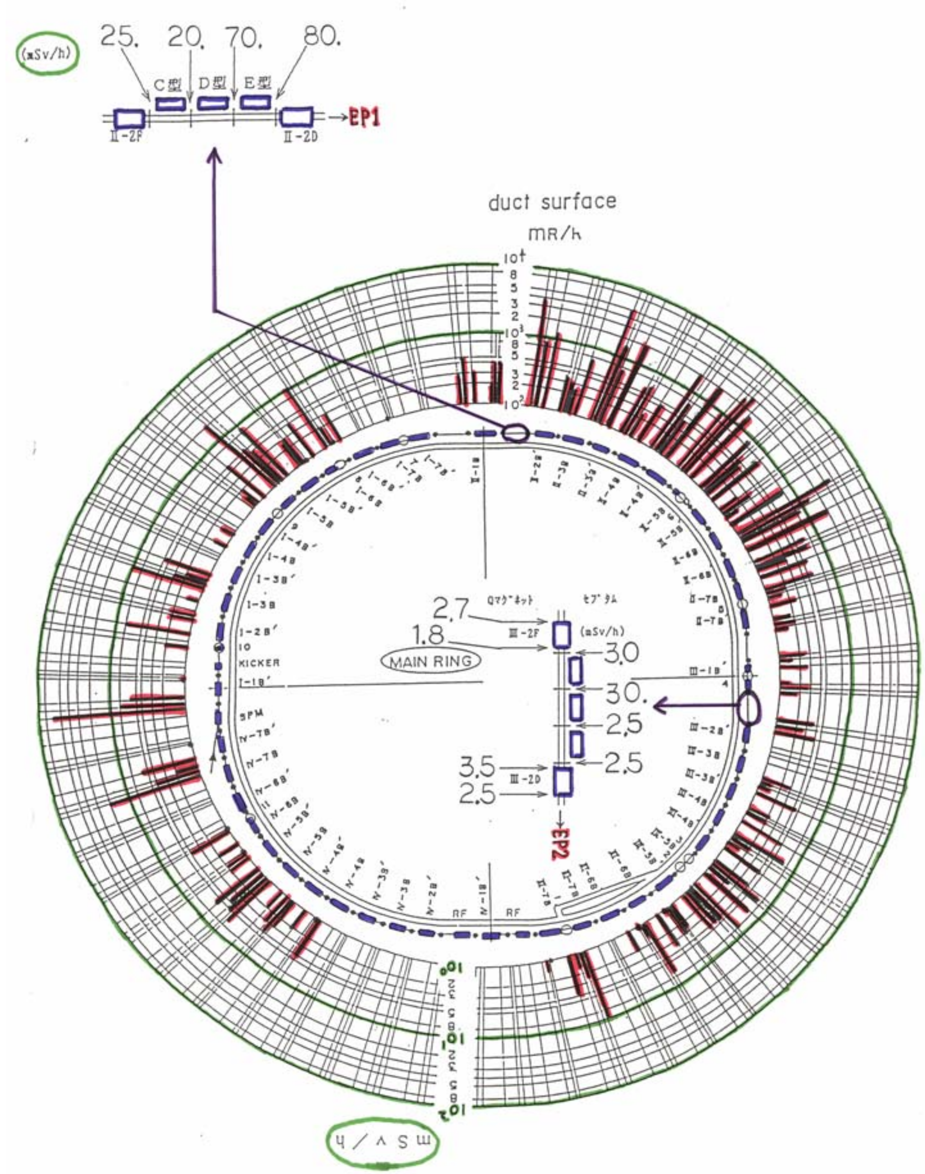
Beam Stop Date:

July 12, 2001

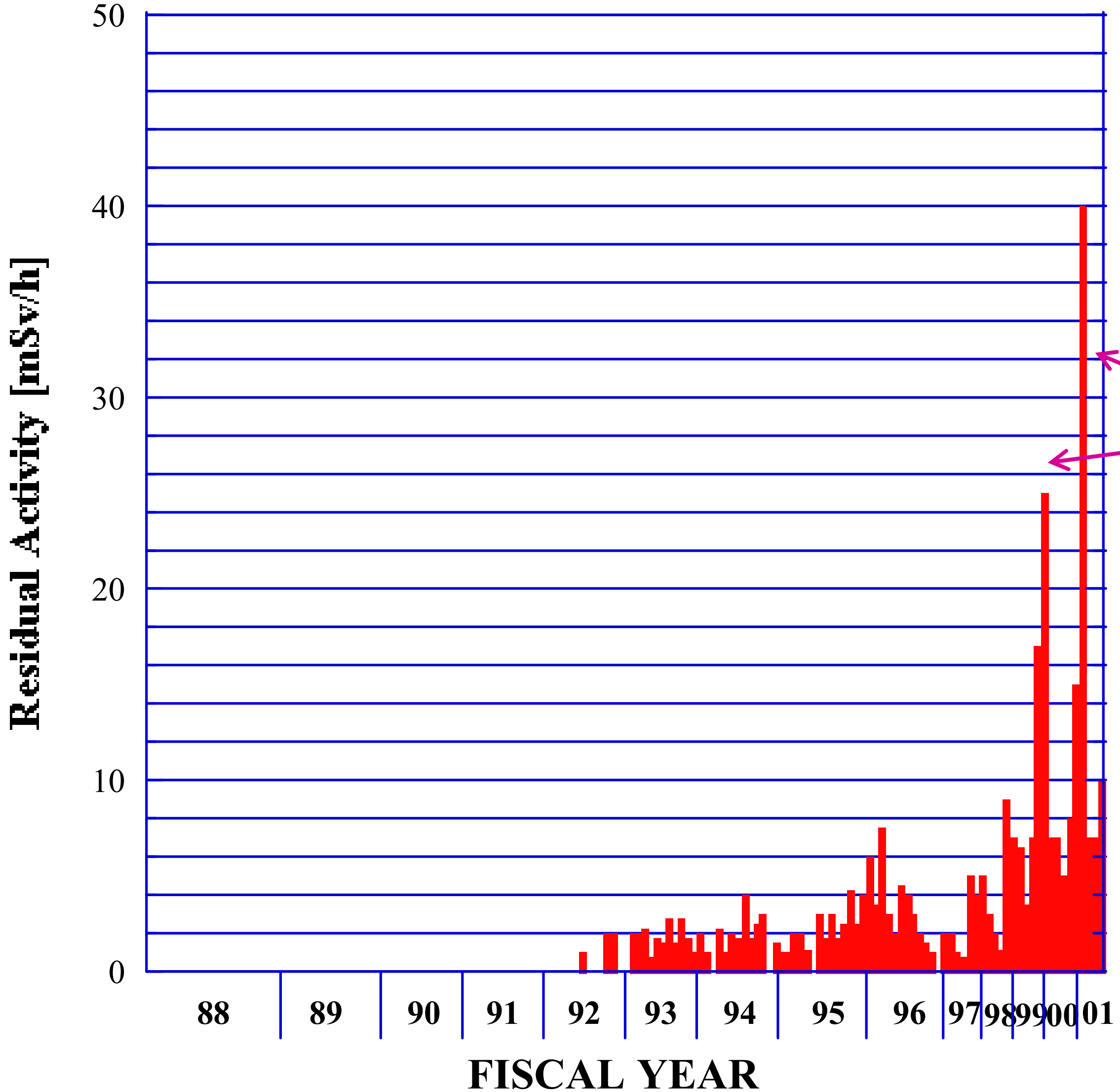
↓ 4 days later

Measured Date:

July 16, 2001



History of the Residual Activity at Main Ring Extraction (EP1)



Measuring Date is varied

Un-normalized!

Usually 3 or 4 days later

Sometime 1 days later

MR Extraction Septum Magnet Trouble

(Schedule) EP2 main/EP1 sub →July 26, 1999

- (July 10) **DC Separator Trouble (main reason)**
- **Troubles of Septum Magnet D and E (EP2)**

↓ • No Spare (EP2 stop, EP1 only)

- (Schedule: EP1 mode (Oct.1→March 24)

↓ • (from April 3:EP2 Mode)

(March 29 & 30, 2000)

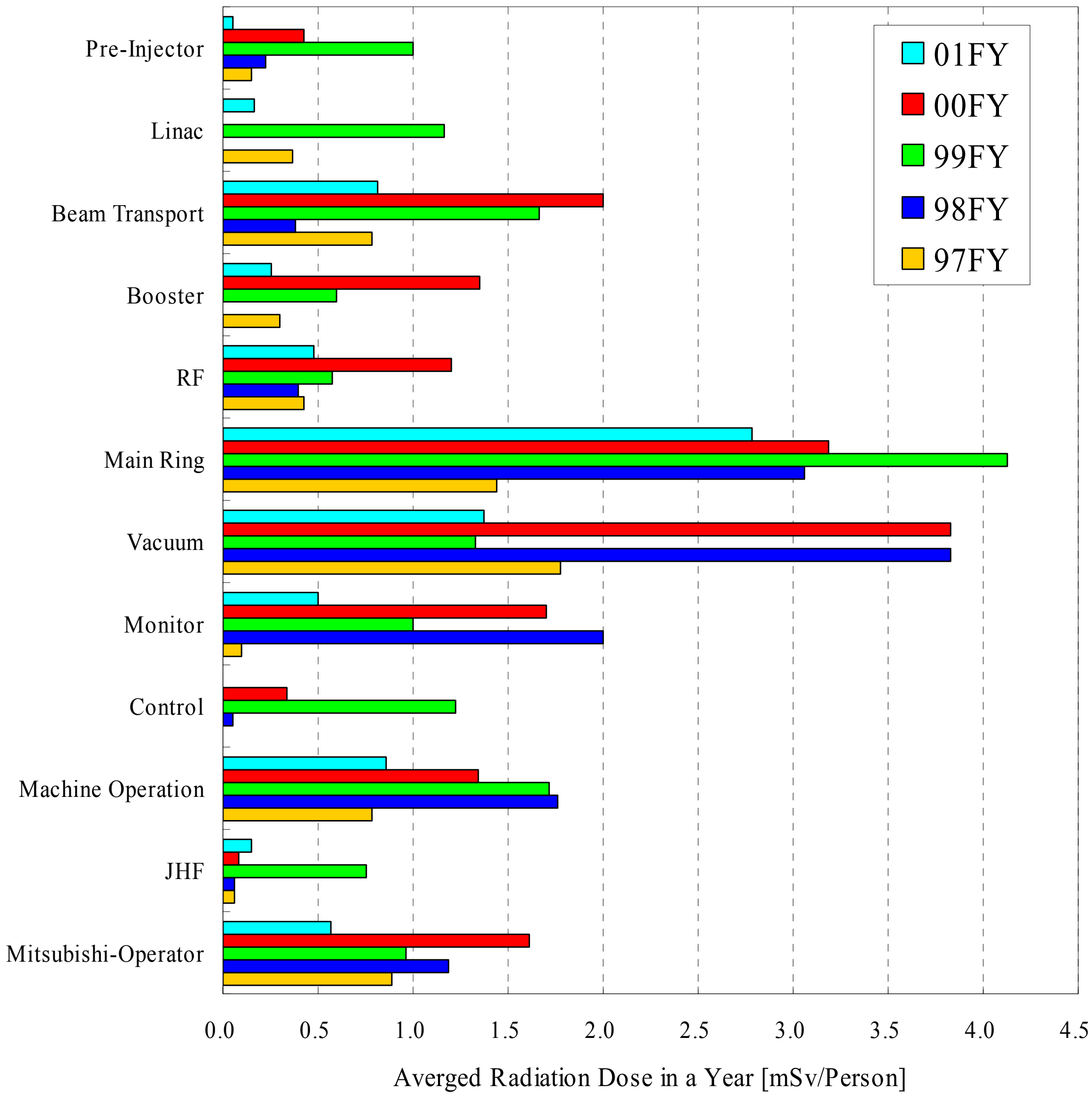
- (1) Remove Septum D & E from EP2
- (2) Move Septum D & E from EP1 to EP2

Dose of PS Maintenance Group

Dose in a Year

KEK rule: 20mSv/year

Alarm Level: 7mSv/year



Order List for Changing Magnet

PS member: real = 56 ⟶ Simple example = 20

Order	Name	Age (year) Y	Total Dose 89～02 (mSv) S
1	A	41	1.18
2	B	40	1.58
3	C	52	2.44
4	D	50	2.71
5	E	63	3.55
6	F	51	3.57
7	G	37	3.66
8	H	48	4.79
9	I	56	4.79
10	J	26	5.20
11	K	41	6.02
12	L	49	6.80
13	M	50	7.24
14	N	42	8.98
15	O	37	9.70
16	P	57	24.48
17	Q	35	32.98
18	R	59	36.00
19	S	40	57.53
20	T	55	66.91

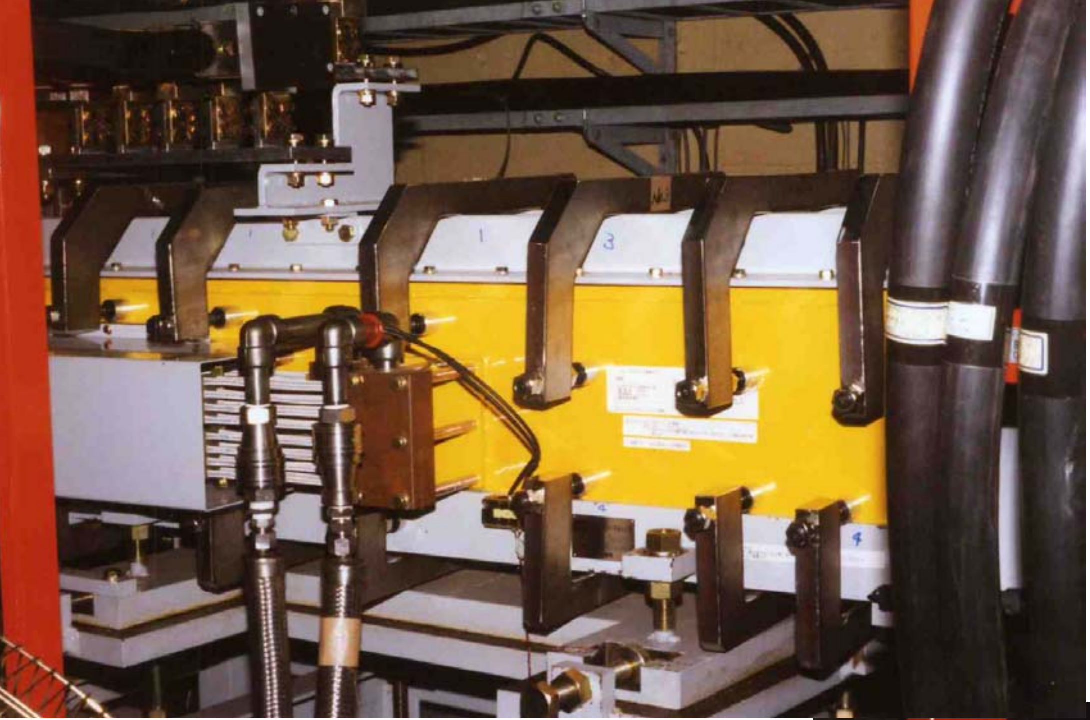
$N = S$

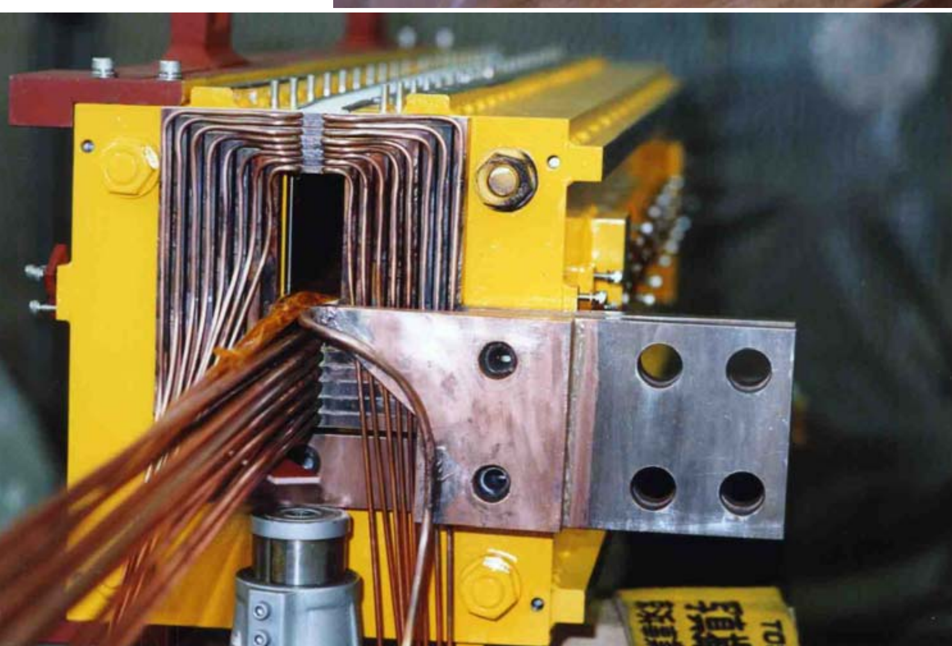
Order	Name	Age (year) Y	Total Dose 89～02 (mSv) S	Working Time (hour) H	Point N
1	B	40	1.58	9.5	9
2	A	41	1.18	15.9	11
3	D	50	2.71	14.0	14
4	H	48	4.79	2.8	14
5	C	52	2.44	16.6	14
6	I	56	4.79	7.4	14
7	F	51	3.57	12.4	15
8	G	37	3.66	6.9	15
9	E	63	3.55	16.9	15
10	L	49	6.80	1.6	18
11	K	41	6.02	4.1	20
12	J	26	5.20	2.3	20
13	M	50	7.24	7.3	22
14	N	42	8.98	4.1	28
15	O	37	9.70	1.0	31
16	P	57	24.48	0.0	53
17	R	59	36.00	0.0	74
18	Q	35	32.98	0.0	107
19	T	55	66.91	1.00	151
20	S	40	57.53	0.0	173

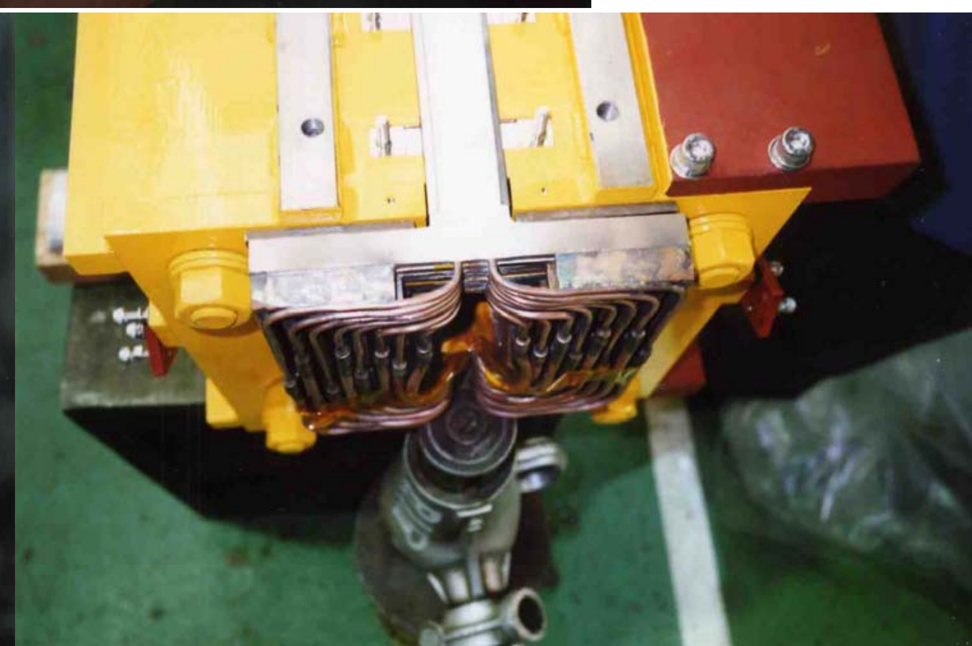
$N = S(-Y/20+5)+H/2$

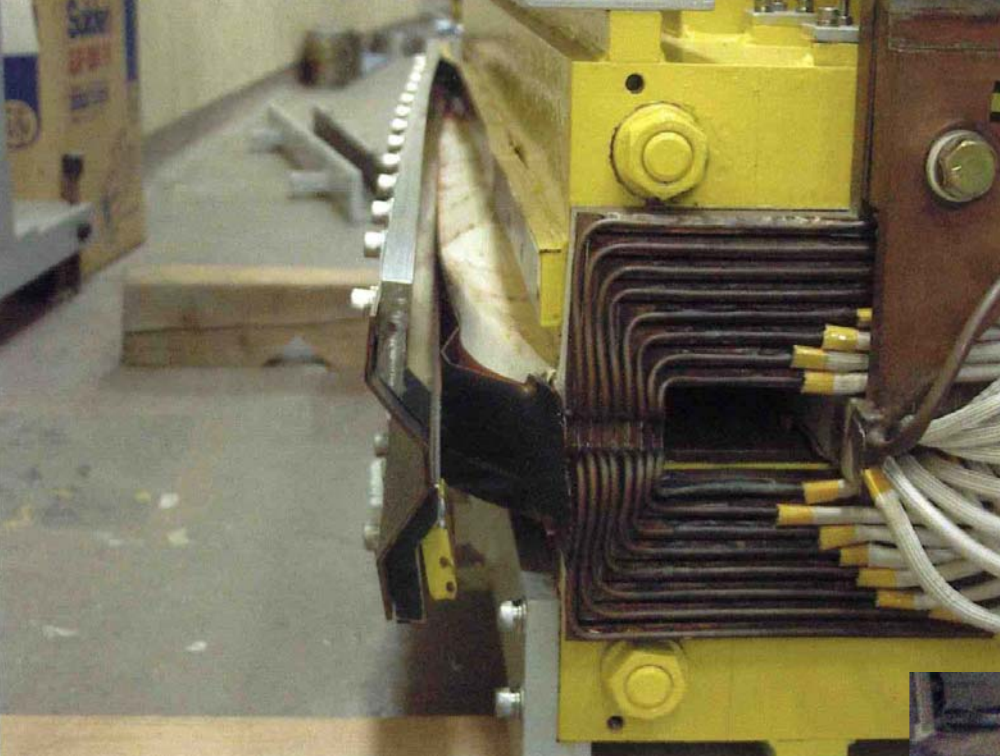
Order	Name	Age (year) Y	Total Dose 89～02 (mSv) S	Working Time (hour) H	Point N
20	E	63	3.55	16.9	41
14	I	56	4.79	7.4	45
19	C	52	2.44	16.6	48
17	D	50	2.71	14.0	49
16	F	51	3.57	12.4	49
9	H	48	4.79	2.8	50
15	B	40	1.58	9.5	51
18	A	41	1.18	15.9	53
7	L	49	6.80	1.6	54
13	M	50	7.24	7.3	57
12	G	37	3.66	6.9	59
10	K	41	6.02	4.1	61
11	N	42	8.98	4.1	69
8	J	26	5.20	2.3	72
5	O	37	9.70	1.0	75
1	P	57	24.48	0.0	83
2	R	59	36.00	0.0	103
3	Q	35	32.98	0.0	153
6	T	55	66.91	1.00	183
4	S	40	57.53	0.0	215

$N = （S+14）*（-Y/20+5)+H/2$









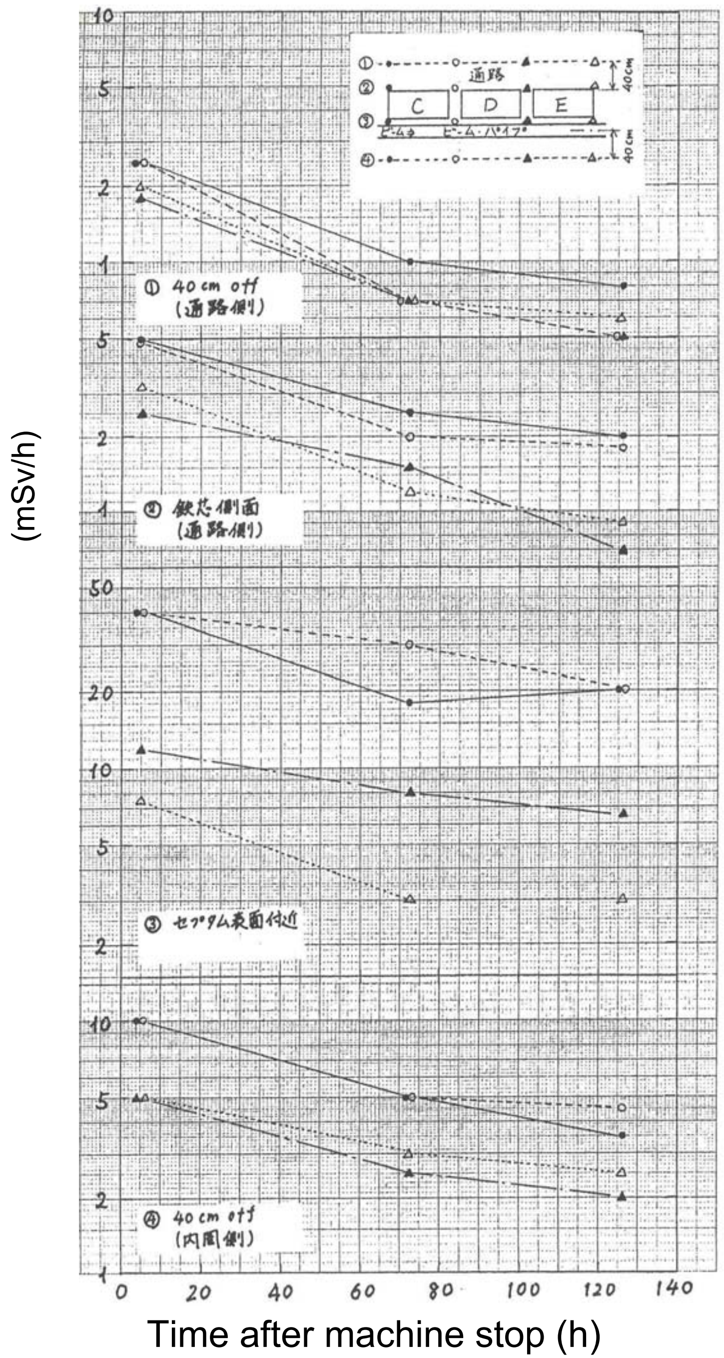
Man Power and Radiation Dose for Maintenance

Maintenance Work	Days	Total Man Power	Radiation Dose (mSv)		
			Total	Av.	Max
(1) Water Leak at EP1 Septum E	5	23	5.05	0.22	0.90*
(2) Replacement of the Electrode at EP2 ESS	6	46	5.12	0.11	0.78
(3) Removement of the EP1 Septum A, B	6	25	2.93	0.11	0.57*
(4) Maintenance of the Main Magnet Cooling System	4	33	3.74	0.11	0.76
(5) Maintenance of the EP1/EP2 septum C, D, E	8	40	7.36	0.18	1.37*

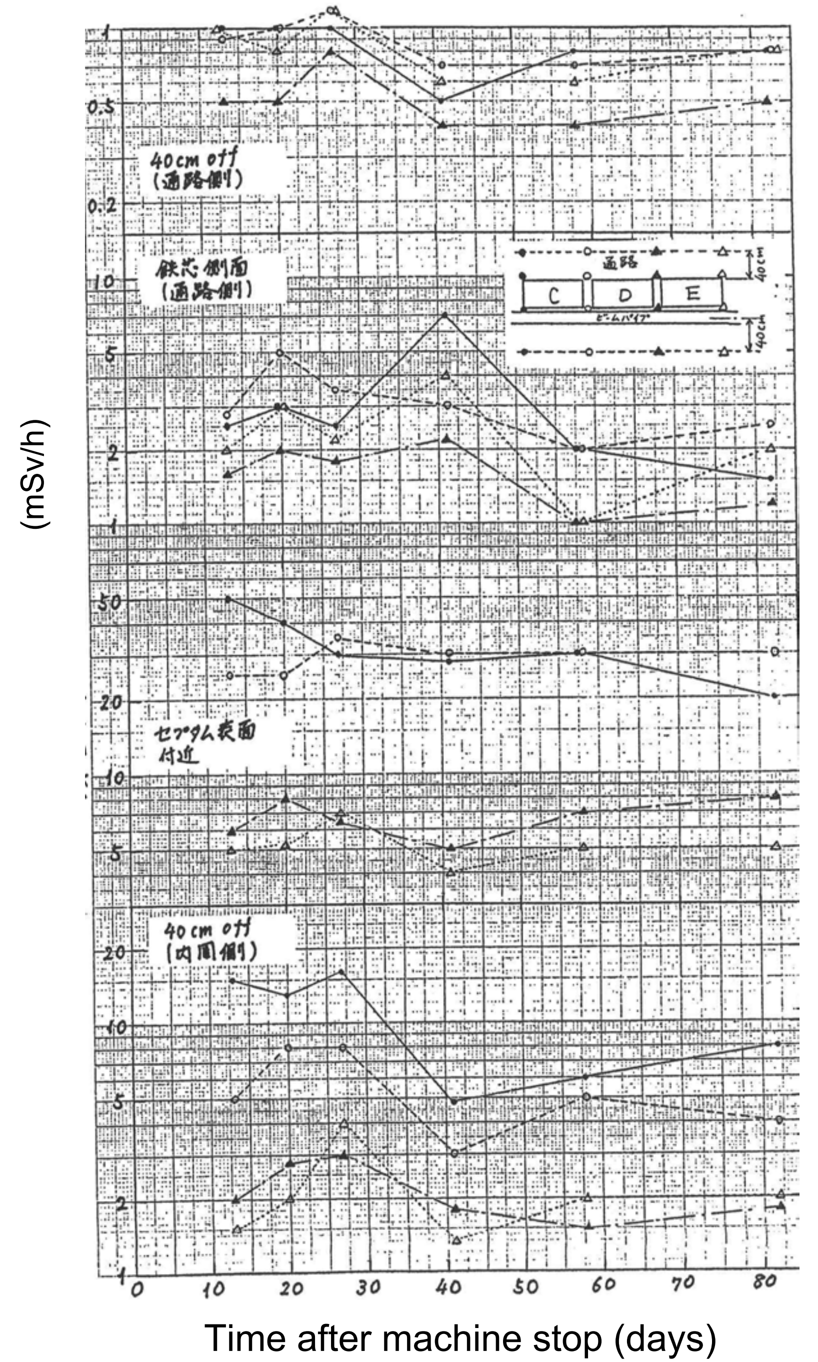
Beam Intensity and Beam Loss at KEK 12-GeV PS

Run No.	Operation Period	Operation Mode		Accelerated ($\times 10^{12}$ ppp)	Ext. Intensity ($\times 10^{12}$ ppp)	Beam Loss ($\times 10^{12}$ pps)	Beam Loss (kW)
310-2	'02 9/26 ~ 10/29	EP1 Slow	4.0	3.5	2.5	0.25	0.48
311-1	10/29 ~ 11/19	EP2 Slow	4.0	2.8	1.9	0.23	0.43
311-2	11/19 ~ 12/17			3.0	2.1	0.23	0.43
312	12/17 ~ 12/25	EP1 Fast	2.2	6.3	5.7	0.27	0.52
313-1	'03 1/16 ~ 2/12			6.1	5.6	0.23	0.44
313-2	2/12 ~ 3/11			7.1	6.5	0.27	0.52
313-3	3/11 ~ 3/31			7.4	6.7	0.32	0.61
314	4/ 1 ~ 4/25			7.3	6.6	0.32	0.61
315-1	5/13 ~ 6/ 9			6.8	6.2	0.27	0.52
315-2	6/ 9 ~ 6/24			6.3	5.9	0.18	0.35
316	6/24 ~ 7/22	EP1 Slow	4.0	3.1	2.1	0.25	0.48
317-1	9/30 ~ 10/27	EP1 Fast	2.2	6.4	5.9	0.23	0.44
317-2	10/27 ~ 11/25			6.6	6.2	0.18	0.35
317-3	11/25 ~ 12/25			6.8	6.3	0.23	0.44
318	'04 1/15 ~ 2/16			6.8	6.2	0.27	0.52
319-1	2/16 ~ 3/ 8	EP2 Slow	4.0	3.5	3.2	0.075	0.14
319-2	3/ 8 ~ 4/ 1						

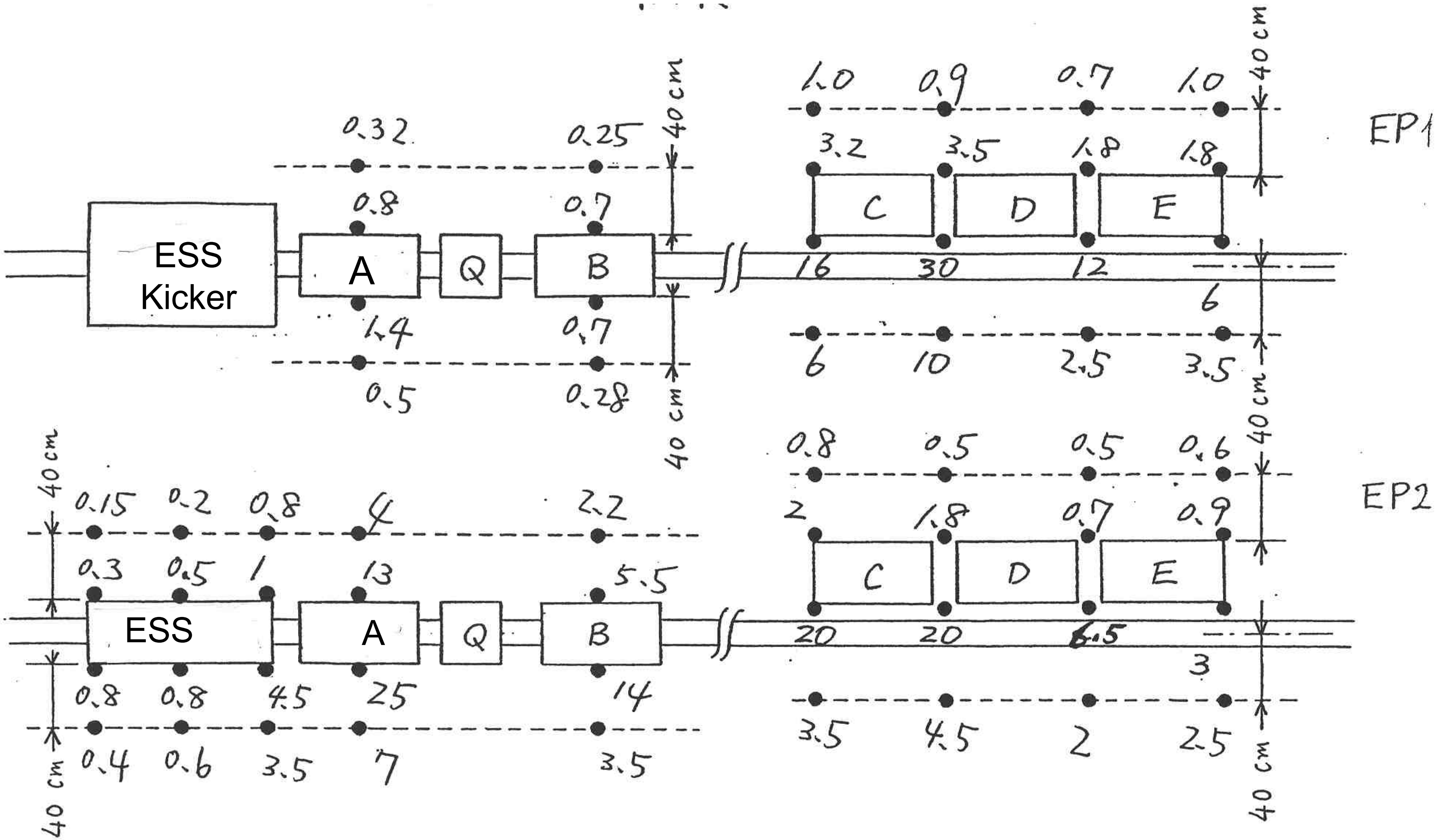
Radiation around EP2 septum C, D, E (2004 March)



Radiation around EP1 septum C, D, E (2003 July-Sep.)



Radiation level at beam line



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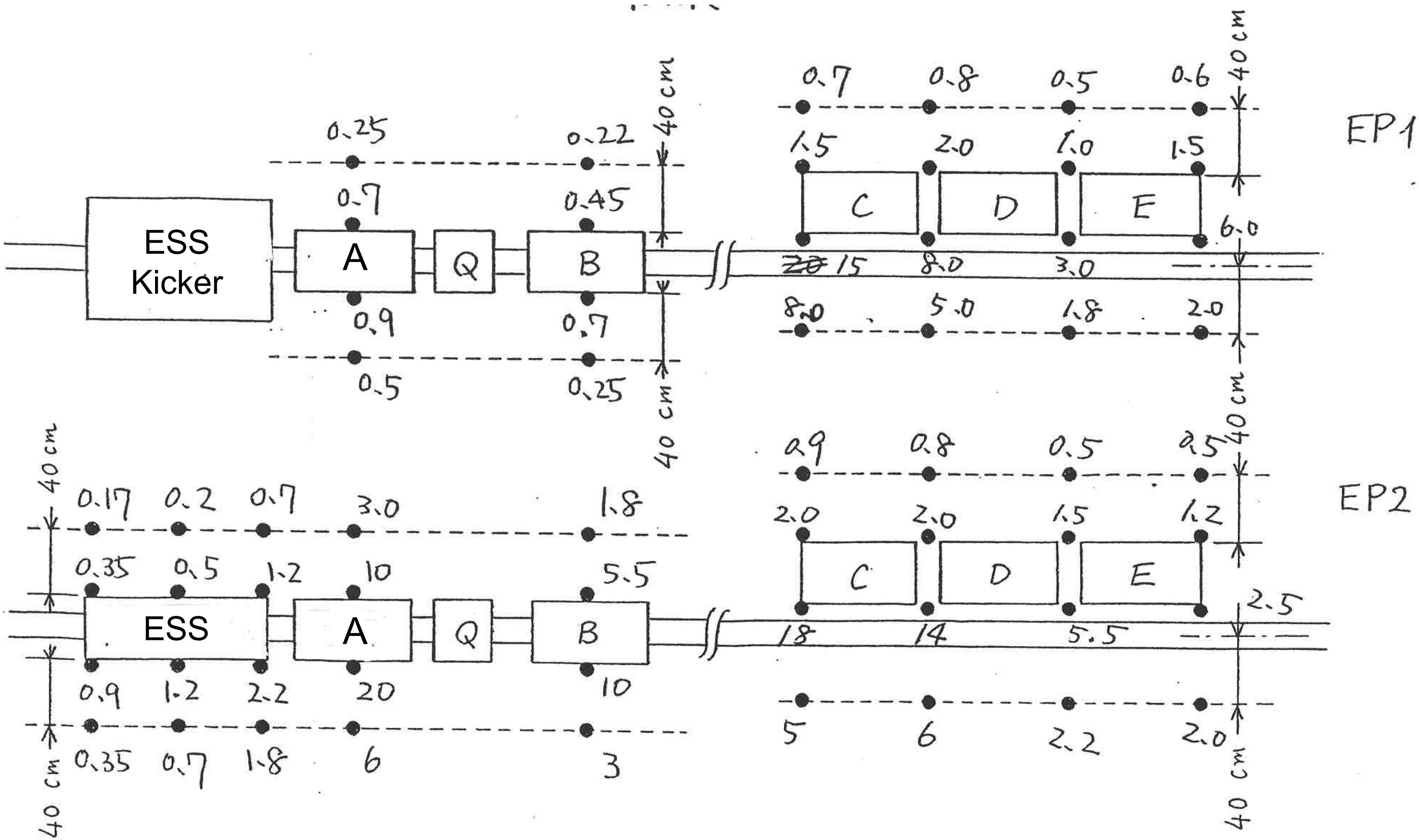
Radiation level at beam line



2004.5.14

Conclusion

PS main ring will be shut down on the end of this year.

PS booster will be also shut down on the March 2006.

Operation and Maintenance Experiences at the KEK-PS should be important lesson to J-PARC.